APPENDIX B—HEAT TREAT STUDY OF INCONEL 718

B.1 COARSE GRAIN AMS 5663.

B.1.1 HEAT TREAT PROCEDURE.

Samples were removed from the fully heat-treated high pressure turbine (HPT) case used to supply coarse-grained Inconel 718 material to the test program. Five soak cycles at 1750°F were used, varying in length from 1 to 30 hours. The material was exposed to 1 to 10 cycles with a maximum exposure of 30 hours at temperature. Conversations with several repair shops suggest that it would be rare for a case in service to be exposed to 30 hours at 1750°F, although this was possible with long-life cases. The cooling rate from a solution was added as a factor. The ideal is to cool at rates greater than or equal to 40°F per minute, but it is common to cool at rates between 10° and 20°F per minute. On rare occasions very slow cooling rates have been used. At the completion of each cycle, the sample was aged per the standard 1325°F (8 hrs) FC to 1150°F (8 hrs). While heat-up rates can vary, established controls should keep the variations small. Heat-up rates were not varied in this evaluation.

B.1.2 EVALUATION PROCEDURE.

A section of each heat-treated sample was mounted in bakelite mounts and examined via light metallography. A qualitative assessment of the amount of needle delta present was then made. With time these assessments were consolidated into four categories. No attempt was made to perform a quantitative assessment of the amount of needle delta phase generated on the material.

B.1.3 RESULTS.

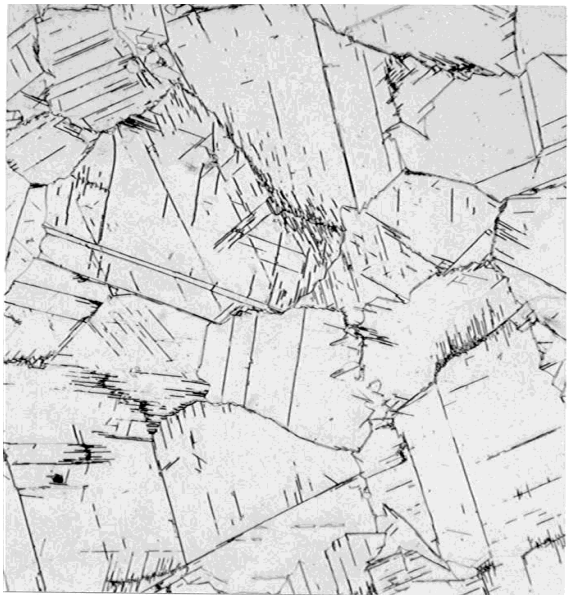
The following table presents a matrix of heat treat conditions and metallographic results. Select examples of the metallographic observations are presented on the following page.

			Amount of Needle Delta		
Cycle (hrs at 1750°F)	No. of Cycles	Total Time at 1750°F*	≥40°F per minute	10° to 20°F per minute	2° to 5°F per minute
1	1	1	Low-Mod.	Low-Mod.	Mod.-High
1	2	2	Low-Mod.	Low-Mod.	Mod.-High
1	5	5	Moderate	High	Very High
1	10	10	High	Very High	Very High
2	2	4	Low-Mod.	High	High
2	5	10	Very High	Very High	High
5	1	5	Moderate	n.d.	Mod.-High
5	2	10	High	n.d.	High
10	1	10	High	n.d.	High
10	3	30	Very High	n.d.	Very High
30	1	30	Very High	n.d.	Very High

*Beyond the initial first hour of fully heat-treated material at start of the evaluation.
n.d. = not done

B.1.4 CONCLUSIONS.

Between the cooling rates more typically experienced when processing cases, a slower cooling rate did result in the precipitation of more needle delta phase. Within any cooling rate the effect of more cycles at shorter times did not seem to be a factor. Total time at temperature was the primary factor with the amount of needle delta phase that was precipitated.



One (1 hr) cycle Fast Cool 200X

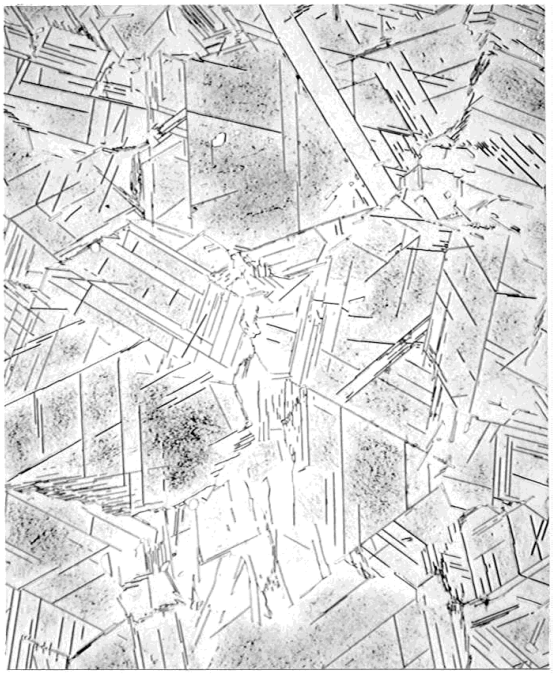
One (1 hr) cycle Slow Cool 200X

Five (1 hr) cycles Fast Cool 200X

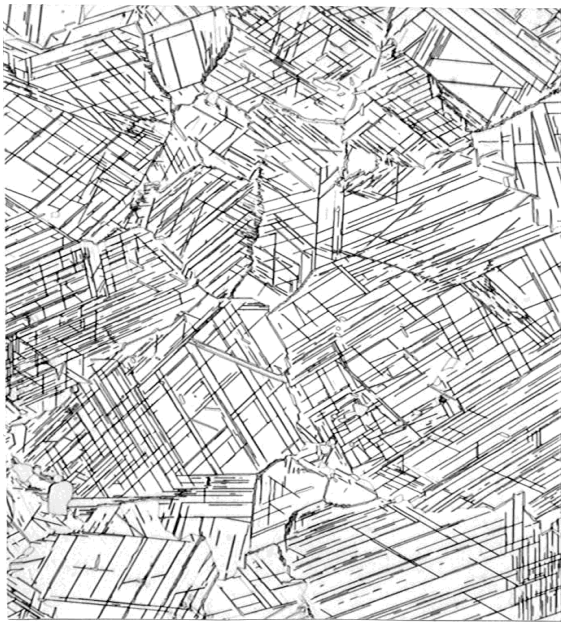
Five (1 hr) cycle Slow Cool 200X

FIGURE B-1. TYPICAL MICROSTRUCTURES ILLUSTRATING DELTA CONCENTRATION IN FULLY HEAT-TREATED COARSE GRAIN AMS 5663 WITH A TOTAL OF 1 (UPPER) AND 5 (LOWER) HOURS AT THE 1750°F SOLUTION TEMPERATURE (Material was both fast cooled (left) and slow cooled (right) from solution prior to precipitation aging.)

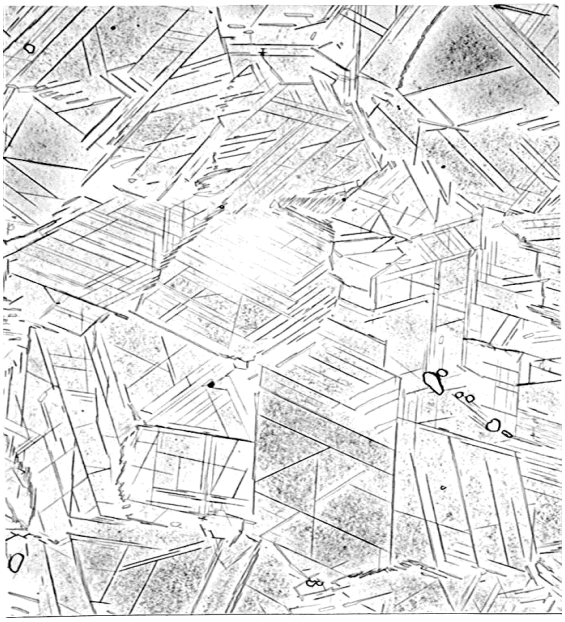
Ten (1 hr) cycles Fast Cool 200X



Five (2 hr) cycles Slow Cool 200X



Three (10 hrs) cycles Fast Cool 200X



One (30 hrs) cycles Slow Cool 200X

FIGURE B-2. TYPICAL MICROSTRUCTURES ILLUSTRATING DELTA CONCENTRATION IN FULLY HEAT-TREATED COARSE GRAIN AMS 5663 WITH A TOTAL OF 10 (UPPER) AND 30 (LOWER) HOURS AT THE 1750°F SOLUTION TEMPERATURE (Material was both fast cooled (left) and slow cooled (right) from solution prior to precipitation aging.)

B.2 FINE GRAIN AMS 5663.

B.2.1 HEAT TREAT PROCEDURE.

Samples were removed from the fully heat-treated barstock case used to supply fine-grained Inconel 718 material to the test program. The heat treat exposure matrix was exactly the same as that used with the coarse grain material described in section B.1. As with the coarse grain material, a maximum exposure of 30 hours at temperature was selected. Again this was guided by conversations with several repair shops that suggested 30 hours of total exposure would more then cover most cases.

B.2.2 EVALUATION PROCEDURE.

A section of each heat-treated sample was mounted in bakelite mounts and examined via light metallography. A qualitative assessment of the amount of needle delta present was then made. With time these assessments were consolidated into four categories. No attempt was made to perform a quantitative assessment of the amount of needle delta phase generated on the material.

B.2.3 RESULTS.

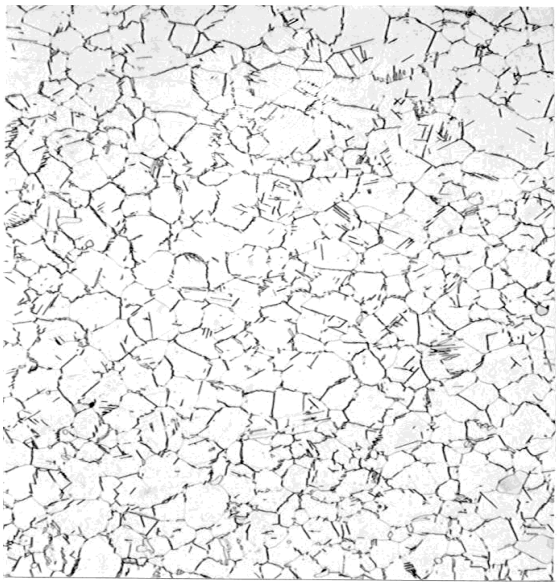
The following table presents a matrix of heat treat conditions and metallographic results. Select examples of the metallographic observations are presented on the following page.

Cycle (hrs at 1750°F)	No. of Cycles	Total Time at 1750°F *	Amount of Needle Delta		
			⩾40°F per minute	10° to 20°F per minute	2° to 5°F per minute
1	1	1	Low-Mod.	Low-Mod.	Low-Mod.
1	2	2	Low-Mod.	Low-Mod.	Low-Mod.
1	5	5	Low-Mod.	Low-Mod.	Low-Mod.
1	10	10	Low-Mod.	Low-Mod.	Low-Mod.
2	2	4	Low-Mod.	Low-Mod.	Low-Mod.
2	5	10	Low-Mod.	Low-Mod.	Low-Mod.
5	1	5	Low-Mod.	n.d.	Low-Mod.
5	2	10	Low-Mod.	n.d.	Low-Mod.
10	1	10	Low-Mod.	n.d.	Low-Mod.
10	3	30	Low-Mod.	n.d.	Low-Mod.
30	1	30	Low-Mod.	n.d.	Low-Mod.

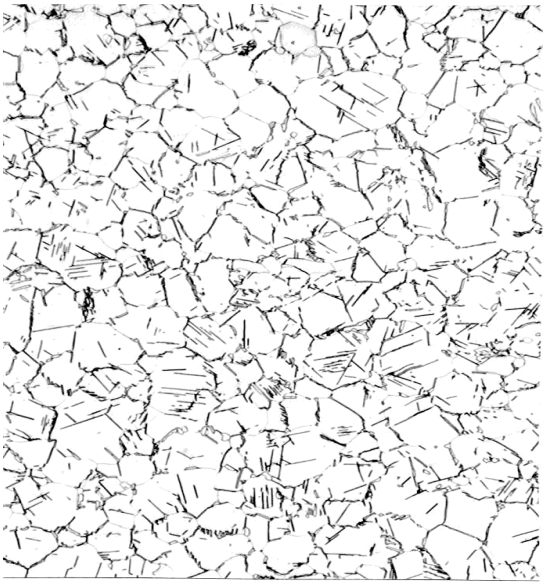
*Beyond initial 1hour of fully heat-treated material at start of the evaluation.
n.d. = not done

B.2.4 CONCLUSIONS.

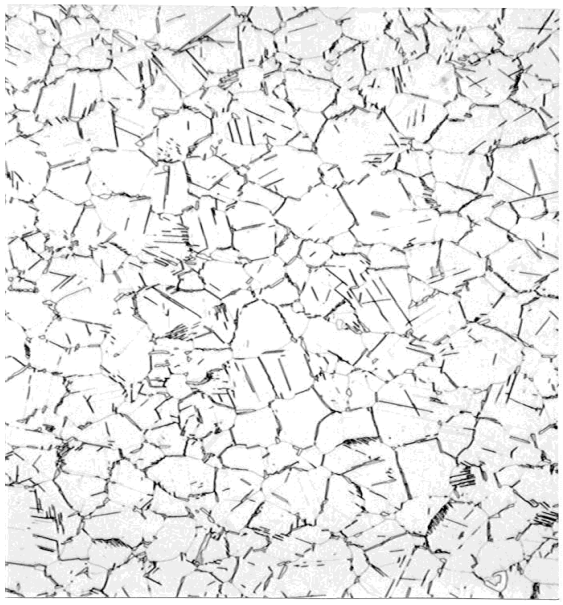
Very little needle delta phase precipitated within the fine grain material. This was true at both the grain boundary and intragranular regions. Further studies would be necessary to determine the reason for this, but it may be related to the fact that the fine grain barstock used in this evaluation had a considerable amount of globular delta phase in its grain boundaries. It is possible this reduced the drive to precipitate additional delta phase.



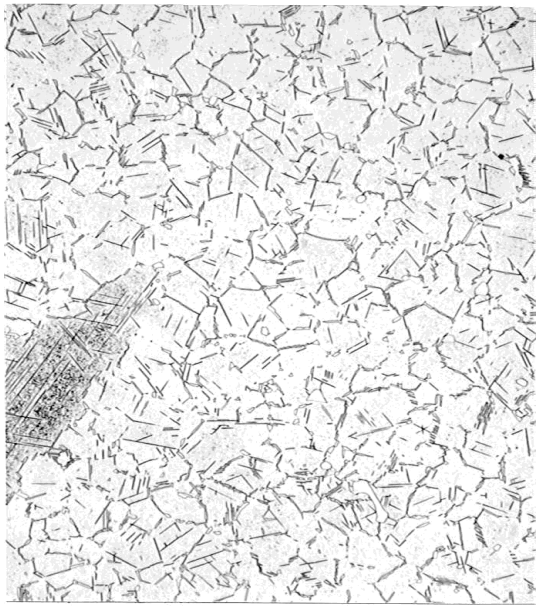
One (1 hr) cycle Fast Cool 200X



Ten (1 hr) cycles Fast Cool 200X



Three (10 hrs) cycles Fast Cool 200X



Three (10 hrs) cycles Slow Cool 200X

FIGURE B-3. TYPICAL MICROSTRUCTURES OF FULLY HEAT-TREATED FINE GRAIN AMS 5663 WITH 1 (UPPER LEFT), 10 (UPPER RIGHT), AND 30 (LOWER) TOTAL HOURS AT 1750°F (All were fast cooled from solution except that illustrated in the lower right photomicrograph.)

B.3 PWA 1469 AND INCONEL 718 WELDS.

B.3.1 HEAT TREAT PROCEDURE.

Previous in-house studies had shown that the cast form of Inconel 718 responds much slower than the wrought form regarding precipitation of needle delta phase. This is especially true for HIP castings where the homogenized matrix combined with no residual energy results in very slow precipitation of delta phase. Segregated castings, including welds, tend to experience delta precipitation that is concentrated, if not limited, to the interdendritic regions. The solidification process segregates and enriches these areas in niobium. For these reasons the exposure matrix for the cast+HIP Inconel 718 (PWA 1469) and Inconel welds was simplified from that used for the wrought material described in sections A and B of this appendix. Total time of exposure was limited to 40 hours for both Inconel 718 welds and cast+HIP Inconel 718. Cooling rate from solution was 10° to 20°F per minute for all exposures

B.3.2 EVALUATION PROCEDURE.

A section of each heat-treated sample was mounted in bakelite mounts and examined via light metallography. A qualitative assessment of the amount of needle delta present was then made. With time these assessments were consolidated into four categories. No attempt was made to perform a quantitative assessment of the amount of needle delta phase generated on the material.

B.3.3 RESULTS.

The following table presents a matrix of heat treat conditions and metallographic results. Select examples of the metallographic observations are presented on the following page.

Cycle (hrs. at 1750°F)	No. of Cycles	Total Time at 1750°F*	Inconel 718 Weld Fusion Zone	Cast+HIP Inconel 718
1	1	1	Mod. - High	Low-Mod.
1	2	2	n.d.	n.d.
1	5	5	n.d.	Low-Mod.
1	10	10	Mod. - High	Moderate
2	2	4	n.d.	n.d.
2	5	10	Mod. - High	n.d.
5	1	5	n.d.	n.d.
5	2	10	n.d.	n.d.
5	8	40	n.d.	High
10	1	10	n.d.	Moderate
10	3	30	High	n.d.
10	4	40	n.d.	High
30	1	30	High	n.d.
40	1	40	n.d.	High

*Actual time for welds; Additional time for fully heat-treated cast+HIP material.
n.d. = not done

B.3.4 CONCLUSIONS.

Results confirmed earlier studies regarding the reaction of the cast forms of Inconel 718 with additional exposures to the 1750°F solution temperature. Even where there was a high concentration of needle delta in the weld material, it was restricted to the interdendritic core and grain boundary areas. Most of the delta that precipitated in the cast+HIP material was mainly at the grain boundaries, but there was some intragranular precipitation, especially at the large MC carbides.

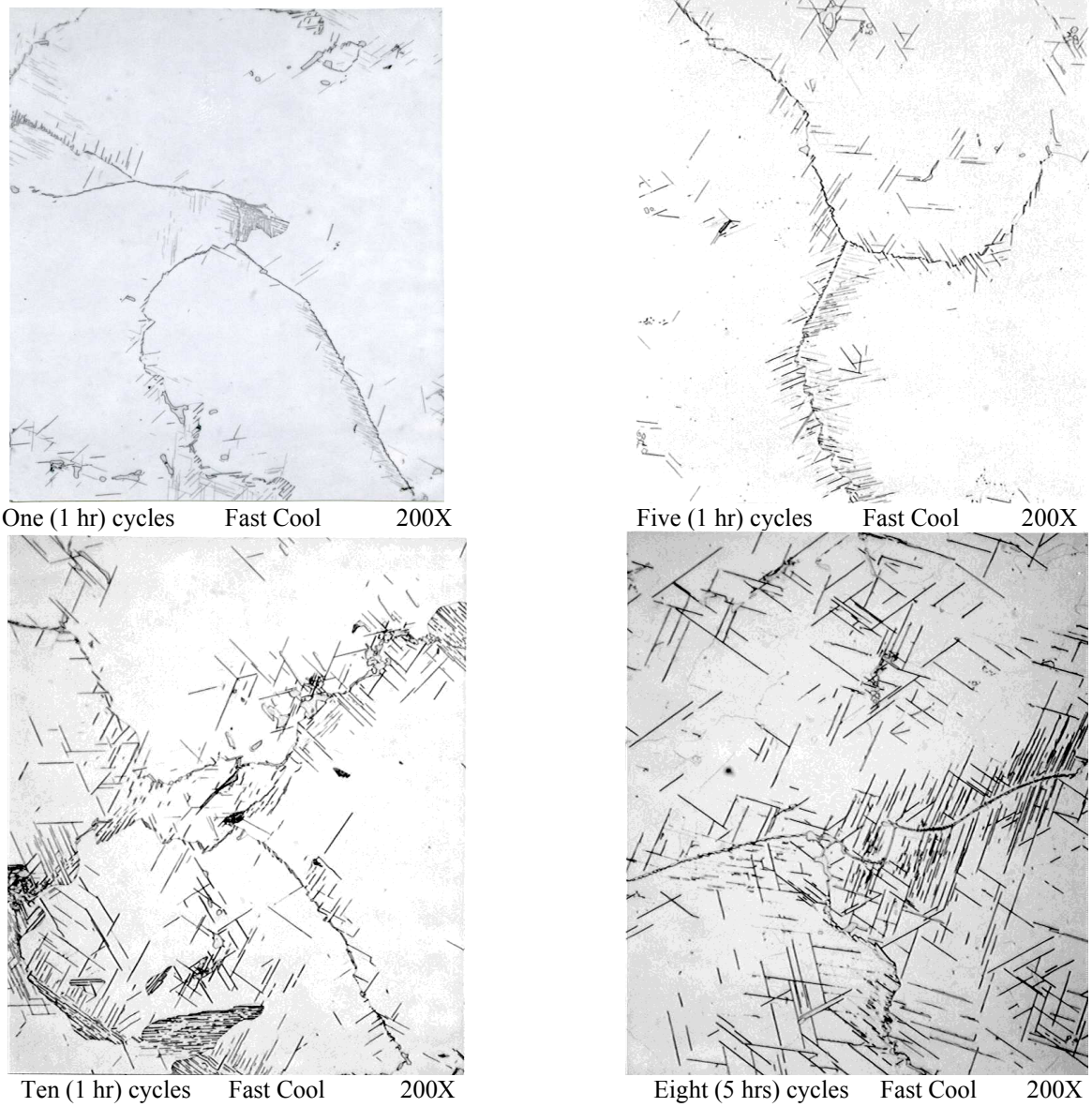
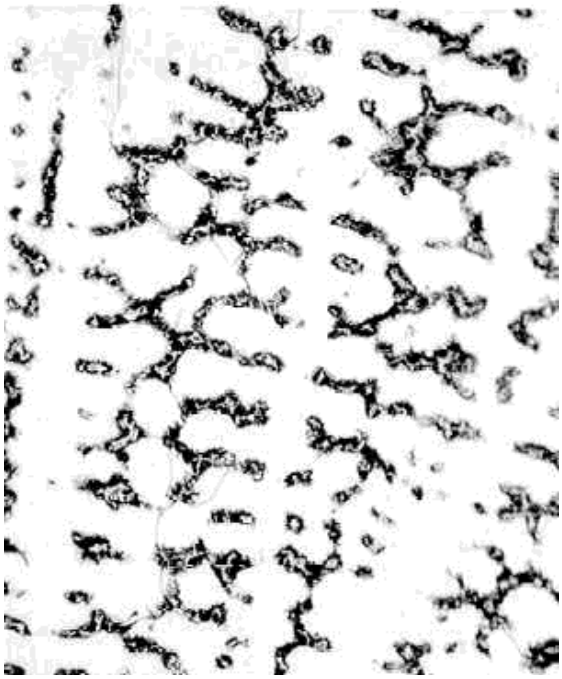
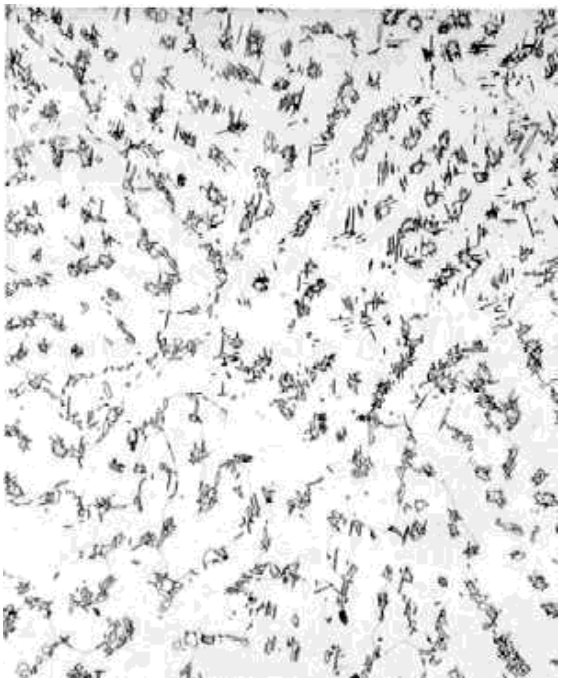


FIGURE B-4. TYPICAL MICROSTRUCTURE OF FULLY HEAT-TREATED PWA 1469 (CAST+HIP INCONEL 718) WITH 1 (UPPER LEFT), 5 (UPPER RIGHT), 10 (LOWER LEFT), AND 40 (LOWER RIGHT) HOURS AT THE 1750°F SOLUTION TEMPERATURE



Weld Fusion Zone 1 Hour Cycle 200X



Weld Fusion Zone 10 Hour Cycle 200X

Weld Fusion Zone 30 Hour Cycle 200X

FIGURE B-5. TYPICAL MICROSTRUCTURE OF FULLY HEAT-TREATED INCONEL 718 WELD FUSION ZONE WITH 1 (UPPER LEFT), 10 (UPPER RIGHT), AND 30 (LOWER LEFT) HOURS AT THE 1750°F SOLUTION TEMPERATURE